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The relationship of muscle fiber type and mass to maximal power production and the maintenance of power (endurance time to exhaustion) at 36, 55, and 73% of maximal power was investigated in 18 untrained but physically active male subjects. Power output was determined at constant velocity (60 RPM) on a high intensity cycle ergometer instrumented with force transducers and interfaced with a computer. Fat free mass was determined by hydrostatic weighing, fat free thigh volume by water displacement and skinfold measurement, and percentage and area of type II fibers from biopsies of the vastus lateralis. Maximal power averaged 771 $\pm$ 149 W with a range of 527-1125 W. No significant correlations were found among percentage of type II fibers, relative area of type II fibers, or fat free thigh volume and maximal power or endurance times to exhaustion at any percentage of maximal power. Weak but significant relationships were found for fat free mass with both maximal power ($r=0.57$) and endurance time at 73% of maximal power ($r=0.47$). These results show maximal power to be more dependent on factors related to body size than muscle fiber characteristics.

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Factors in maximal power production

and in exercise endurance relative to maximal power

by

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ABSTRACT

The relationship of muscle fiber type and mass to maximal power production and the maintenance of power (endurance time to exhaustion) at 36, 55, and 73% of maximal power was investigated in 18 untrained but physically active male subjects. Power output was determined at constant velocity (60 RPM) on a high intensity cycle ergometer instrumented with force transducers and interfaced with a computer. Fat free mass was determined by hydrostatic weighing, fat free thigh volume by water displacement and skinfold measurement, and percentage and area of type II fibers from biopsies of the vastus lateralis. Maximal power averaged 771 ± 149 W with a range of 527-1125 W. No significant correlations were found among percentage of type II fibers, relative area of type II fibers, or fat free thigh volume and maximal power or endurance times to exhaustion at any percentage of maximal power. Weak but significant relationships were found for fat free mass with both maximal power ($r=0.57$) and endurance time at 73% of maximal power ($r=-0.47$). These results show maximal power to be more dependent on factors related to body size than muscle fiber characteristics. The low correlations for so many of the relationships, however, suggest that individuals employ different combinations of these factors in the physiological performance strategies utilized for the generation of high power outputs.

Index Terms: Anaerobic exercise, skeletal muscle fiber morphology, fat free thigh volume, cycle ergometry.

Introduction

One of the most important considerations in human exercise performance is the ability to produce power. Research, however, has principally focused on the energy sources available for muscular contraction rather than upon the resulting mechanical power output. The ability to determine maximal leg power production has been limited by the unavailability of ergometers that could provide the resistances adequate to cover the higher exercise intensities of which humans are capable.

Maximal power outputs have been calculated from measurements made during stair-climbing (21) and constant load cycle ergometry (2) but these tests have been criticized because the velocity of muscular contractions was not controlled. The isokinetic dynamometer (e.g. Cybex) has been used extensively to measure maximal torque at various contraction velocities but has also been criticized due to limitations in the interpretability and utility of the data generated (13,37). More recently, the development of high-intensity cycle ergometers fitted with transducers to measure pedal forces has allowed the accurate measurement of maximal leg power during constant velocity, concentric exercise (15,18,23,28).

Several studies have assessed factors considered to be important in the ability of humans to produce maximal power but all have utilized either stair-climbing (19), constant load cycle ergometry (14), or the isokinetic dynamometer (8,13,16,26,33,34) as the modes of exercise. Skeletal muscle mass and fiber composition are factors that have been found to be significantly correlated with maximal torque or power development (14,16,19,26,33,34). However, such

significant relationships have not always been observed (8,13). Furthermore, significant correlations have often been found when the subject sample consisted solely of highly trained strength and endurance athletes (16,19,34), thereby eliminating any variance contribution from the middle portion of the standard curve. To date, no studies are available assessing the contribution of such variables to maximal power during concentric, constant velocity, cycling exercise in nonathletic subjects.

In the present study, a specially constructed cycle ergometer was employed which permitted the testing of subjects over a full range of power production at constant pedal-crank velocities. The purposes of this investigation were: 1) to evaluate variables previously found to be related to the production of maximal leg power, and 2) to identify factors important for the maintenance of power at various percentages of maximum, in normally active, male subjects.

Methods

Subjects. Eighteen healthy male subjects volunteered to participate in this study following an explanation of the experimental procedures and the possible risks involved. Signed informed consent was obtained prior to participation. Subjects were neither well-trained nor sedentary but were occasionally to moderately active as most took part in some form of regular physical activity. Each subject reported to the laboratory on several occasions prior to any data collection and was thoroughly familiarized with all testing equipment and procedures.

Cycle ergometer and power production. Torque and power generated during constant velocity cycling exercise were determined using a specially constructed

cycle ergometer (18). The ergometer was instrumented with force transducers and interfaced with a computer for data collection and processing as described previously (15). Maximal power was determined for each subject as the highest one-revolution average power generated by a subject pedalling with maximal effort for five revolutions on the cycle ergometer while velocity was maintained at 60 rpm. Three tests of 5 revolutions were performed with 20 minutes of rest between tests. The average of the two closest results was taken as maximal power. The subject was seated in a rigid metal armchair behind the crankshaft to provide back support. The distance from the chair to pedal crank was set for each subject so that the knee would never quite fully extend.

On separate days following maximal power determination, subjects were tested in random sequence for endurance times to exhaustion at 36, 55, and 73% of maximal power. For each test, cycle resistance was set at the percentage of maximal power at which the subject was to exercise. The subject was required to generate power at this level in order to maintain the crank speed at 60 rpm. Both a panel meter in front of the subject indicating speed and a metronome were used to aid the subject in maintaining pedal cadence. The test ended when the speed decreased to 58 RPM or less for 7s. The 7s were subtracted from the total time of exercise. The test, re-test reliabilities for endurance time to exhaustion (n= 10 subjects) were 0.92, 0.95, and 0.96 at 36, 55, and 73% of maximal power, respectively.

Muscle biopsy procedure. Muscle biopsies, as described by Bergstrom (4) and modified by Evans et al.(11), were taken from the lateral portion of the m. vastus lateralis at least one week prior to power testing. Care was taken to approximate a comparable location in all subjects using a depth of 2 cm. When repeat biopsies were taken, no significant variations in fiber-type distribution were

observed. The samples were oriented, mounted on a freezing chuck in embedding medium, frozen in isopentane cooled in liquid N_2, and stored at -120°C for subsequent analysis. Cross sections (12 μm) were cut in a cryostat (American Optical) maintained at -20°C. Histochemical reactions were carried out for myofibrillar ATPase activity at pH 4.3, 4.6, and 10.3 (6,30). Muscle fibers were divided into three groups (types I, IIA, and IIB) based on the stability of ATPase activity in the preincubation medium. Fiber type percentages were computed using a Zeiss Interactive Digital Analysis System (ZIDAS, Carl Zeiss, FRG) which involved projection of cross sections onto a digitizing tablet interfaced with a computer. An average of 992 (range 389-1732) fibers per subject were counted to calculate percent fiber type.

The cross-sectional areas of all intact type I and type II fibers were determined using NADH-tetrazolium reductase stained sections (24) with the aid of a digitizing tablet and the ZIDAS system for computation. The mean area of type I and type II fibers was determined for each subject and the mean area occupied by type II fibers was calculated and expressed as the total area occupied by the type II fibers (32). Capillary density ($cap \cdot mm^{-2}$) and capillaries per fiber ($cap \cdot fib^{-1}$) were determined from amylase-periodic acid-Schiff stained fibers as previously described (1).

<u>Anthropometry</u>. Subject's height, body mass, body composition, and thigh volume were determined after an overnight fast prior to power testing. Fat free mass (FFM) was determined by a standard hydrostatic weighing technique using a load cell interfaced with a desktop computer (12). Residual lung volume was determined by the oxygen dilution method as described by Wilmore et al. (36). Right thigh volume from the gluteal furrow to just above the patella was determined by water displacement (17). To calculate fat free thigh volume

(FFTV), skinfold thickness was measured on the anterior and posterior thigh in the midline at the one third subischial height level (35).

Aerobic and anaerobic power. Aerobic power ($\dot{V}O_2max$) was determined using a discontinuous protocol. Subjects initially pedalled at 235 W for 4-5 min with speed maintained at 60 RPM. The intensity was then increased in 30 W increments until a plateau occurred in oxygen uptake. Each exercise bout lasted 3-5 min and was followed by a 5-10 min rest period. The cycle ergometer and subject positioning were the same as that for determining maximal power. Expired gas was collected in Douglas bags and volume measured by a Tissot spirometer. Oxygen and carbon dioxide concentrations were measured by Applied Electrochemistry S3-A and Beckman LB-2 analyzers, respectively. Heart rate was monitored via ECG using a modified V_5 lead.

Maximal power outputs from the Wingate test (2) and an isokinetic endurance test (33) were also determined for all subjects to compare values from these tests to those obtained from the high-intensity cycle ergometer. The Wingate test was performed on a mechanically braked cycle ergometer (Monark) modified so that resistance could be instantaneously applied to the flywheel. The subject pedalled maximally for 30s at a resistance of 4.41 joules•pedal revolution^{-1}•kg body mass^{-1}. Mean power output was calculated for the first 5s (peak power) and the entire 30s period (mean power). For the isokinetic endurance test, the Cybex dynamometer was set at a velocity of 180 degrees•s^{-1}. Subjects performed 50 maximal knee extensions during a 60s period. Peak torque (Nm) was averaged for the first three contractions to determine highest peak torque and for the entire 50 contractions to determine mean peak torque. Power output was computed as torque times the angular velocity in radians•sec^{-1}.

Statistical analysis. For each variable, group data are presented as mean ± standard deviation. Pearson product-moment correlation coefficients were calculated to assess the interrelationships between the independent variables and both maximal power and endurance time for submaximal power production at the three percentages of maximal power. Multivariate regression analysis was also utilized to examine selected variable relationships. Statistical significance was set at the $p<.05$ level.

Results

The descriptive data (means ± SD) for the eighteen subjects are presented in Table 1. The subjects provided a very heterogeneous group based upon physiologic and morphologic characteristics. Maximal power, for example, ranged from 527-1125 W (mean 771 ± 149 W) while muscle fiber distribution ranged from 26-70% type II in vastus lateralis.

Relationships of the morphologic and physiologic variables with maximal power production are shown in Table 2. Significant correlations ($p<.01$) were observed between maximal power and power output values from the Wingate test ($r=0.79$-0.80) and peak powers developed during the isokinetic endurance test ($r=0.68$-0.70). In addition, a weak but significant negative relationship was demonstrated between maximal power and aerobic power expressed relative to body mass ($r=-0.45$).

The morphological variables that yielded the highest positive correlations with maximal power were body mass and fat free mass ($r=0.54$ and 0.57, respectively, $p<.02$). No significant relationships were found between maximal power and fat free thigh volume, percent type II or IIA fiber composition of the

vastus lateralis, and percent type II fiber area. Multivariate regression analysis did not significantly improve any of the bivariate relationships between maximal power and the variables presented in Table 2. All two-factor combinations of the above variables were performed and significant multivariate r's were found for body mass and % type II fibers (r=0.55) and fat free mass and % type II fibers (r=0.59). Combining fat free thigh volume and % type II fiber composition yielded a multivariate r of only 0.15.

The individual data points for maximal power and the morphologic variables are presented in Figures 1 and 2. It is apparent that there was no significant relationship between either muscle fiber composition or fiber area and maximal power production (Figure 1). Similarly, fat free thigh volume showed little relationship to maximal power resulting in a low correlation (Figure 2).

The mean endurance times (±SD) to exhaustion at 36%, 55%, and 73% of maximal power were 3.81 ± 1.52 min, 1.15 ± 0.69 min, and 0.42 ± 0.25 min, respectively. The corresponding power output values (means ± SD) were: 280 ± 54 W, 423 ± 85 W, and 560 ± 108 W. These exercise intensities were approximately 104%, 157%, and 207%, respectively, of those which elicited maximal oxygen uptake. Thus maximal oxygen uptake occurred at about 35% of maximal power output.

Table 3 presents correlation coefficients for endurance times at each percentage of maximal power and the morphologic variables. As seen, endurance times demonstrated only significant negative relationships with body mass, fat free mass and maximal oxygen uptake at 55% and 73% maximal power. No significant correlations with any of the variables occurred at 36% maximal power. As in the case of maximal power, multivariate regression analysis did not significantly improve any of the bivariate relationships shown in Table 3.

Discussion

The power output data presented in this paper were obtained using a high-intensity cycle ergometer, the pedals of which were instrumented with strain gauges to enable force to be continuously monitored. This allowed for the direct measurement of torque at constant velocity and precluded any assumptions being made regarding changes in frictional or inertial forces during maximal power testing. In the investigation of power production, this approach has definite advantages over other methods which employ movements involving acceleration where muscles contract at an optimal velocity for only a brief period of time (3,21) or are reliable only at velocities below approximately 25% of maximal contraction velocity (33).

The maximal power developed (771 W) was strikingly similar to mean values reported by Sargeant et al. (28) and McCartney et al. (22) (approximately 750 and 758 W at 60 rpm, respectively) who also employed constant velocity cycle ergometers. These authors, however, obtained the highest power outputs for one revolution cycling at between 110-120 rpm. Despite such findings, a velocity of 60 rpm was chosen for the present study since this is the frequency most often employed in cycle ergometer tests. In addition, Suzuki (31) found that mechanical efficiency is reduced in individuals with high percentages of type I fibers when pedalling frequency is increased from 60 to 100 rpm. At 60 rpm no difference existed in efficiency between individuals with a predominance of type I compared with type II fibers.

In agreement with the findings of McCartney et al. (22), considerable intersubject differences were observed in the ability to generate power. Several studies have suggested that these differences are related to such factors as the

composition of fibers in exercising muscle and the absolute mass of the active musculature. The principal findings of this study, however, show these factors to be poorly related to maximal power in normally active, male subjects. With respect to muscle fiber composition, the present data support the recent findings of Froese and Houston (13) as well as others (8,29) who found no significant relationship between type II fibers and peak knee extension torque values. In contrast, a positive correlation has been reported between type II fiber composition of the vastus lateralis and either peak torque values during maximal isokinetic knee extension (16,19,26,33,34) or power outputs from the Wingate test (3,14). Such inconsistensies in studies employing the Cybex dynamometer may result from some authors reporting angle specific torque values while others fail to correct peak torque for either impact artifact or gravity (37). Limitations in fiber type assessment from single biopsy samples may also play a role in the above discrepancies. Recent attention (5,10) has focused on this problem where the precision of fiber type estimations has been shown to be increased by sampling two or more sites or by increasing the number of fibers counted. According to Blomstrand and Ekblom (10), the expected variability for a single biopsy is only about 2% if 1000 fibers are counted. This represents the approximate mean number of fibers counted from the sample taken in this study.

Another factor contributing to inconsistencies among studies relating percent fiber type to peak torque or maximal power is in the selection of the subject population. Several studies (16,19,34) have utilized various athletic groups including power- and endurance-trained athletes where the former generally have

moderate to high percentages of type II fibers and the latter high percentages of type I fibers (27). Thus a large difference in values is obtained in subjects who comprise the extremes in exercise performance and type of physical training program. While a fairly heterogeneous group was studied herein, particularly with respect to fiber type and body size, the subjects did not represent the extremes in athletic endeavors which characterized the other studies.

In addition to muscle fiber composition, a number of studies have found such indicators of body size as body mass (8,25), fat free mass (25), and leg mass measured anthropometrically (25) or by computerized tomography (16,22) to be related to maximal torque development. With the exception of the study by McCartney et al. (22), all used the Cybex isokinetic dynamometer. The present results agree with the above studies with respect to body mass and fat free mass but failed to show a significant relationship between fat free thigh volume and maximal power production as previously shown with peak torque (16,22). Reasons for this inconsistency are not clear but may be related to the involvement of different muscle groups in the exercise, in the type of muscular contractions performed, or to the method used to measure thigh volume. The estimate of fat free thigh volume from anthropometric techniques is potentially subject to error. However, Edwards et al.(9) have shown that the cross-sectional area of the thigh from computerized tomography scans is highly related ($r=0.97$) with that measured by anthropometry.

Despite the significant correlations of body mass and fat free mass with peak torque and power, these variables account for less than 35% of the shared variance, suggesting that anthropometric measures are relatively poor predictors of maximal torque or power. However, results from this study agree with others (7,8) that maximal power or torque are more dependent on characteristics of body size than on fiber type composition.

The second major purpose of this investigation was to identify factors important in submaximal exercise endurance (relative to maximal power). To our knowledge, no data are available on endurance times to exhaustion at levels of power production considerably higher than those which elicit maximal oxygen uptake. As was the case with maximal power, no muscle fiber characteristics (% fiber type, % fiber area, capillary density) showed any significant relationship to endurance time at any percentage of maximal power output. These results are in agreement with the data of Litchfield et al.(20) who reported no significant correlations between muscle fiber composition and isometric endurance sustained to exhaustion at forces corresponding to 20%, 50%, and 80% of maximal voluntary contraction in untrained men. These data suggest that variations in the muscle characteristics measured do not account for individual differences in anaerobic endurance performance and that the assessment of such characteristics in untrained subjects is not particularly useful for detecting individuals with high anaerobic potential.

Indicators of body size (body mass and fat free mass) were found to have low, but significant correlations with endurance times to exhaustion as they did with maximal power suggesting that the maintenance of high percentages of maximal power is also more dependent on body size than muscle fiber composition. The inverse relationship further shows that larger subjects are less able to maintain power and thus fatigue faster which agrees with the results of Clarkson et al.(7) who found a negative relationship between body weight and fatigue.

In summary, muscle fiber characteristics and indicators of body size are poorly related to the production of maximal power and the ability to maintain power at high percentages of maximum in normally active, male subjects. Many

complex factors including biomechanical considerations, neuromuscular elements controlling recruitment and firing of motor units, and motivation, in addition to the above, undoubtedly contribute to the development of power. It is concluded, therefore, that individuals use different combinations of these factors and performance strategies to generate high power and, given their variety and complexity, the establishment of a relationship between power and any single one should "not be expected in the intact human model"(13).

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC regulation 70-25 on Use of Volunteers in Research.

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References

1. Anderson, P. Capillary density in skeletal muscle of man. Acta Physiol. Scand. 95: 203-205, 1975.
2. Bar-Or, O. Le test anaerobic de Wingate. Symbioses 13: 157-172, 1981.
3. Bar-Or, O., R. Dotan, O. Inbar, A. Rothstein, J. Karlsson, and P. Tesch. Anaerobic capacity and muscle fiber type distribution in man. Int. J. Sports Med. 1: 82-85, 1980.
4. Bergstrom, J. Muscle electrolytes in man. Scand. J. Clin. Lab. Invest. (Suppl) 68: 1-110, 1962.
5. Blomstrand, E. and B. Ekblom. The needle biopsy technique for fiber type determination in human skeletal muscle - a methodological study. Acta Physiol. Scand. 116: 437-442, 1982.
6. Brooke, M.H. and K.K. Kaiser. Three "myosin ATPase" systems: the nature of pH lability and sulfhydryl dependence. J. Histochem. Cytochem. 18: 670-672, 1970.
7. Clarkson, P.M., J. Johnson, D. Dextradeur, W. Leszczynski, J. Wai, and A. Melchionda. The relationships among isokinetic endurance, initial strength level, and fiber type. Res. Quart. for Exerc. and Sport. 53: 15-19, 1982.
8. Clarkson, P.M., W. Kroll, and A.M. Melchionda. Isokinetic strength, endurance, and fiber type composition in elite American paddlers. Eur. J. Appl. Physiol. 48: 67-76, 1982.
9. Edwards, R.H.T., S. Grindrod, M. Narici, O. Rutherford, and A.J. Sargeant. Assessment of leg muscle size by anthropometry and x-ray computerized tomography. J. Physiol. 353: 4P, 1984.
10. Elder, G.C.B., K. Bradbury, and R. Roberts. Variability of fiber type distributions within human muscles. J. Appl. Physiol. 53: 1473-1480, 1982.

11. Evans, W.J., S.D. Phinney, and V.R. Young. Suction applied to a muscle biopsy maximizes sample size. Med. Sci. Sports 14: 101-102, 1982.

12. Fitzgerald, P.I., J.A. Vogel, J. Miletti, and J.M. Foster. An improved portable hydrostatic weighing system for body composition. US Army Research Institute of Environmental Medicine. Technical Report T4-88, October 1987.

13. Froese, E.A. and M.E. Houston. Torque-velocity characteristics and muscle fiber type in human vastus lateralis. J. Appl. Physiol. 59: 309-314, 1985.

14. Froese, E.A. and M.E. Houston. Performance during the Wingate amaerobic test and muscle morphology in males and females. Int. J. Sports Med. 8: 35-39, 1987.

15. Harman, E., H.G. Knuttgen, and P. Frykman. Automated data collection and processing for a cycle ergometer. J. Appl. Physiol. 62: 831-836, 1987.

16. Johansson, C., R. Lorentzon, M. Sjostrom, M. Fagerlund, and A.R. Fugl-Meyer. Sprinters and marathon runners. Does isokinetic knee extensor performance reflect muscle size and structure? Acta Physiol. Scand. 130: 663-669, 1987.

17. Jones, P.R.M. and J. Pearson. Anthropometric determination of leg fat and muscle plus bone volumes in young male and female adults. J. Physiol. 204: 63-66p, 1969.

18. Knuttgen, H.G., J.F. Patton, and J.A. Vogel. An ergometer for concentric and eccentric muscular exercise. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 53: 784-788, 1982.

19. Komi, P.V., H. Rusko, J. Vos, and V. Vihko. Anaerobic performance capacity in athletes. Acta Physiol. Scand. 100: 107-114, 1977.

20. Litchfield, P.E., R.J. Maughan, and M.A. Nimmo. Isometric endurance capacity and muscle fibre composition in man. J. Physiol.(London) 354: 73P, 1984.

21. Margaria, R., P. Aghemo, and E. Rovelli. Measurement of muscular power (anaerobic) in man. J. Appl. Physiol. 21: 1661-1669, 1966.

22. McCartney, N., G.J.F. Heigenhauser, and N.L. Jones. Power output and fatigue of human muscle in maximal cycling exercise. J. Appl. Physiol.:Respirat. Environ. Exercise Physiol. 55: 218-224, 1983.

23. McCartney, N., G.J.F. Heigenhauser, A.J. Sargeant, and N.L. Jones. A constant-velocity cycle ergometer for the study of dynamic muscle function. J. Appl. Physiol.:Respirat. Environ. Exercise Physiol. 55: 212-217, 1983.

24. Novikoff, A.B., W.Y. Shin, and J. Drucker. Mitochondrial localization of oxidative enzymes: staining results with two tetrazolium salts. J. Biophys. Biochem. Cytol. 9: 47-61, 1961.

25. Nutter, J., and W.G. Thorland. Body composition and anthropometric correlates of isokinetic leg extension strength of young adult males. Res. Quart. for Exerc. and Sport. 58: 47-51, 1987.

26. Ryushi, T. and T. Fukunaga. Influence of subtypes of fast-twitch fibers on isokinetic strength in untrained men. Int. J. Sports Med. 7: 250-253, 1986.

27. Saltin, B., J. Henriksson, E. Nygaard, P. Anderson, E. Jansson. Fiber types and metabolic potentials of skeletal muscles in sedentary men and endurance runners. Ann. NY Acad. Sci. 301: 3-29, 1977

28. Sargeant, A.J., E. Hoinville, and A. Young. Maximum leg force and power output during short term dynamic exercise. J. Appl. Physiol.:Respirat. Environ. Exercise Physiol. 51: 1175-1182, 1981.

29. Schantz, P., E. Randall-Fox, W. Hutchison, A. Tyden, and P.-O. Astrand. Muscle fibre type distribution, muscle cross-sectional area and maximal voluntary strength in humans. Acta Physiol. Scand. 117: 219-226, 1983.

30. Staron, R.S., R.S. Hikida, and F.C. Hagerman. Myofibrillar ATPase activity in human muscle fast-twitch subtypes. Histochem. 78: 405-408, 1983.

31. Suzuki, Y. Mechanical efficiency of fast-and slow-twitch muscle fibers in man during cycling. J. Appl. Physiol.:Respirat. Environ. Exercise Physiol. 47: 263-267, 1979.

32. Tesch, P. Muscle fatigue in man with special reference to lactate accumulation during short term intense exercise. Acta Physiol. Scand. (Suppl) 480: 1-40, 1980.

33. Thorstensson, A., G. Grimby, and J. Karlsson. Force-velocity and fiber composition in human knee extensor muscles. J. Appl. Physiol. 40: 12-16, 1976.

34. Thorstensson, A., L. Larsson, P Tesch, and J. Karlsson. Muscle strength and fiber composition in athletes and sedentary men. Med. Sci. Sports 9: 26-30, 1977.

35. Watson, A.W.S. and D.J. O'Donovan. Factors relating to the strength of male adolescents. J. Appl. Physiol.:Respirat. Environ. Exercise Physiol. 43:834-838, 1977.

36. Wilmore, J.H., P.A. Vodak, R.B. Parr, R.N. Girondola, and J.E. Betting. Further simplification of a method for determination of residual lung volume. Med. Sci. Sports and Exercise 12: 216-218, 1980.

37. Winter, D.A., R.P. Wells, and G.W. Orr. Errors in the use of isokinetic dynamometers. Eur. J. Appl. Physiol. 46: 397-408, 1981.

Table 1. Subject descriptive data (n=18)

	Mean ± SD	Range
Age, yrs	25.4 ± 8.0	20-54
$\dot{V}O_2max$, $m\ell \cdot kg^{-1} \cdot min^{-1}$	46.6 ± 6.2	32.9-59.2
Maximal power, W	771 ± 149	527-1125
Anthropometry		
Body mass, kg	77.7 ± 11.6	63.6-110.5
% Body fat	15.8 ± 5.6	8.4-27.5
Fat free mass, kg	65.1 ± 7.8	52.5-82.0
Fat free thigh volume, ℓ	5.31 ± 0.98	3.89-7.90
Muscle fiber analysis		
% type II	50.0 ± 11.3	26.1-69.8
% type IIA	37.7 ± 8.9	21.2-52.0
% type II area	52.1 ± 12.9	22.9-73.5
Mean type II area, $m^2 \cdot 100$	59.0 ± 11.6	22.9-83.4
Type II area/type I area	1.11 ± 0.21	0.61-1.36
Capillary density, $cap \cdot mm^{-2}$	296.1 ± 54.9	161.7-381.9
Wingate test		
Peak power, W	707 ± 133	510-961
Mean power, W	503 ± 95	320-710
Isokinetic endurance test		
Highest peak power, W	458 ± 102	313-757
Mean peak power, W	295 ± 51	198-421

Table 2. Correlation coefficients and p values between maximal power and various morphologic and physiologic variables

Variable	r	p
Wingate test		
Peak power	0.79	0.001
Mean power	0.80	0.001
Isokinetic endurance test		
Highest peak power	0.70	0.001
Mean peak power	0.68	0.01
Body mass	0.54	0.02
Percent body fat	0.09	0.71
Fat free mass	0.57	0.02
Fat free thigh volume	0.11	0.68
Percent type II fibers	0.16	0.52
Percent type IIA fibers	0.33	0.19
Percent type II area	0.09	0.72
Type II area/type I area	0.16	0.54
Capillary density	-0.35	0.15
$\dot{V}O_2max$, $m\ell \cdot kg^{-1} \cdot min^{-1}$	-0.45	0.05

Table 3. Correlation coefficients for endurance times at percentages of maximal power and morphologic variables.

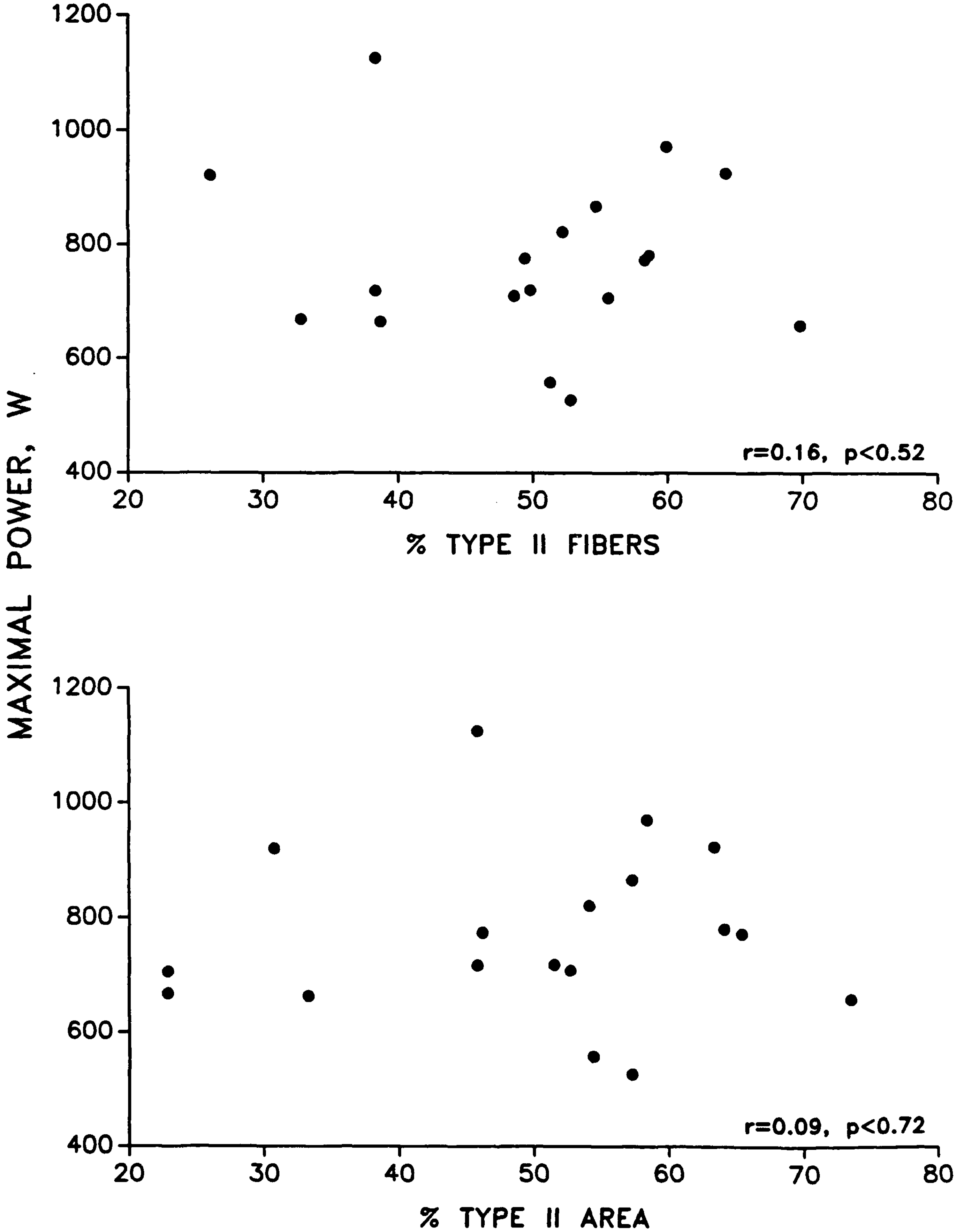
Variable	36%	55%	73%
Body mass	-0.24	-0.47*	-0.49*
Percent body fat	-0.05	-0.21	-0.22
Fat free mass	-0.25	-0.44	-0.47*
Fat free thigh volume	0.20	0.10	0.12
Percent type II fibers	-0.19	-0.15	-0.07
Percent type IIA fibers	-0.44	-0.44	-0.39
Percent type II area	-0.24	-0.16	-0.06
Type II area/type I area	-0.21	-0.09	-0.01
Capillary density	0.29	0.40	0.42
$\dot{V}O_{2}max$, $m\ell \cdot kg^{-1} \cdot min^{-1}$	0.24	-0.51*	-0.51*

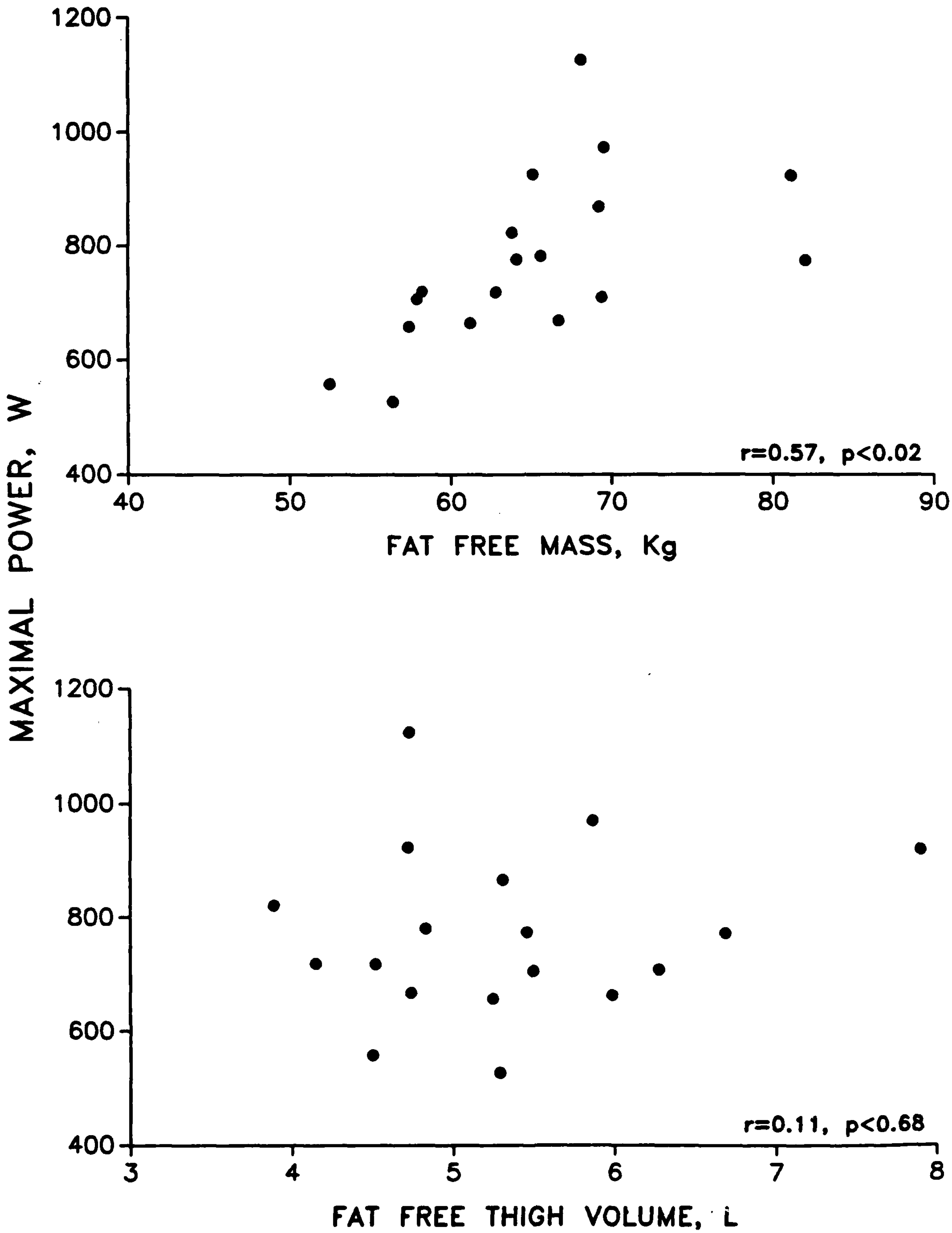
*$p<.05$

FIGURE LEGENDS

Figure 1. Relationship between maximal power production and muscle fiber characteristics.

Figure 2. Relationship between maximal power production and anthropometric measures.


MAXIMAL POWER, W
r=0.16, p<0.52
% TYPE II FIBERS
r=0.09, p<0.72
% TYPE II AREA


MAXIMAL POWER, W
1200
1000
800
600
400
40
50
60
70
80
90
FAT FREE MASS, Kg
r=0.57, p<0.02
3
4
5
6
7
8
FAT FREE THIGH VOLUME, L
r=0.11, p<0.68